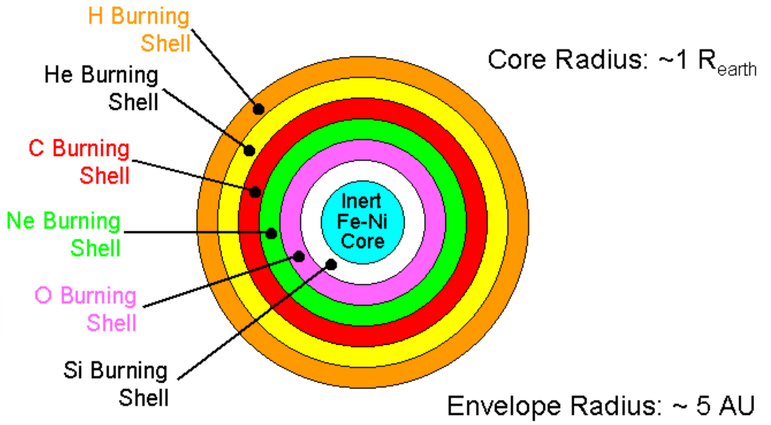
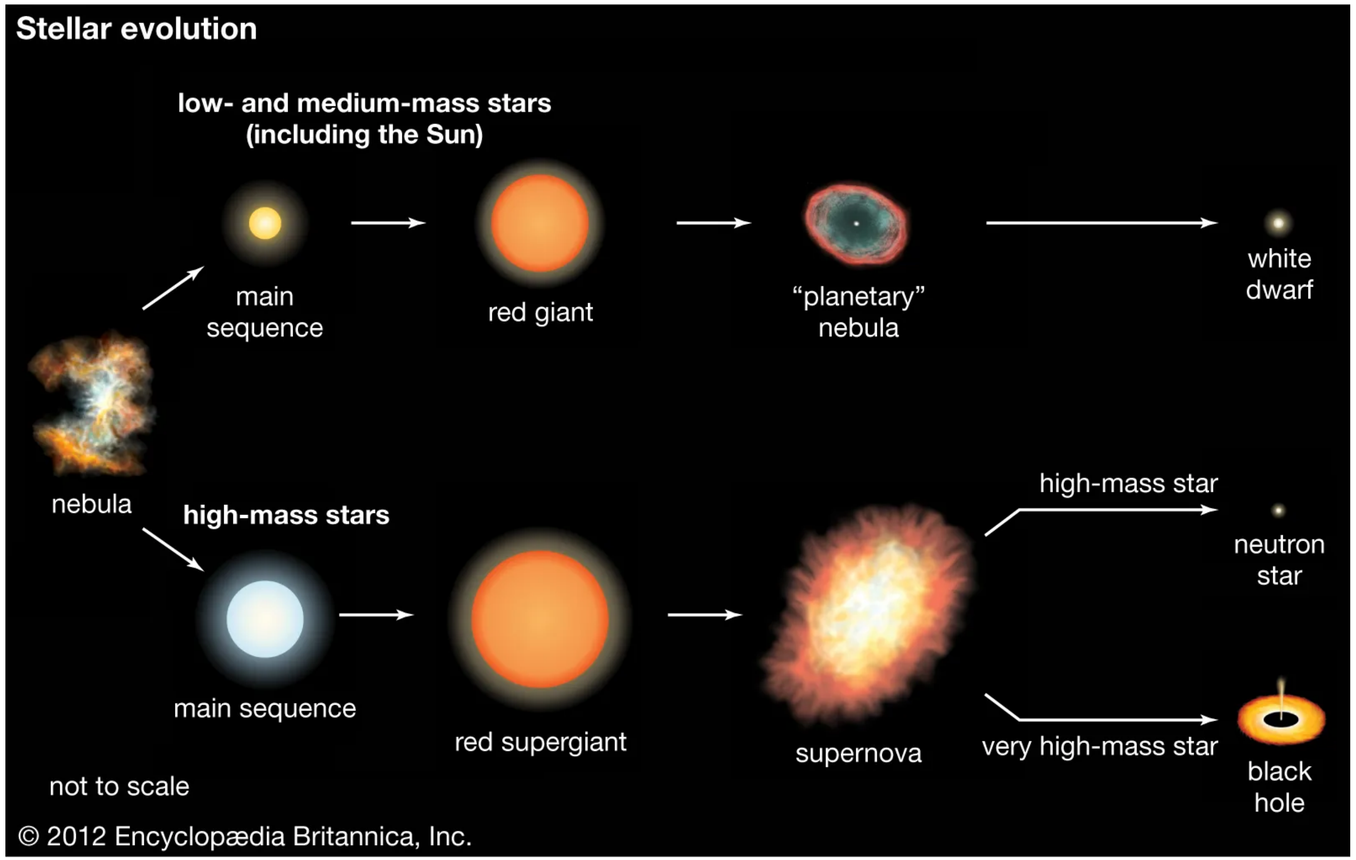
Light Curve Modelling of the peculiar interacting SN 2019vxm

Boróka H. Pál
University of Szeged
Doctoral School of Physics
Department of Medical Physics and Informatics

Massive star evolution

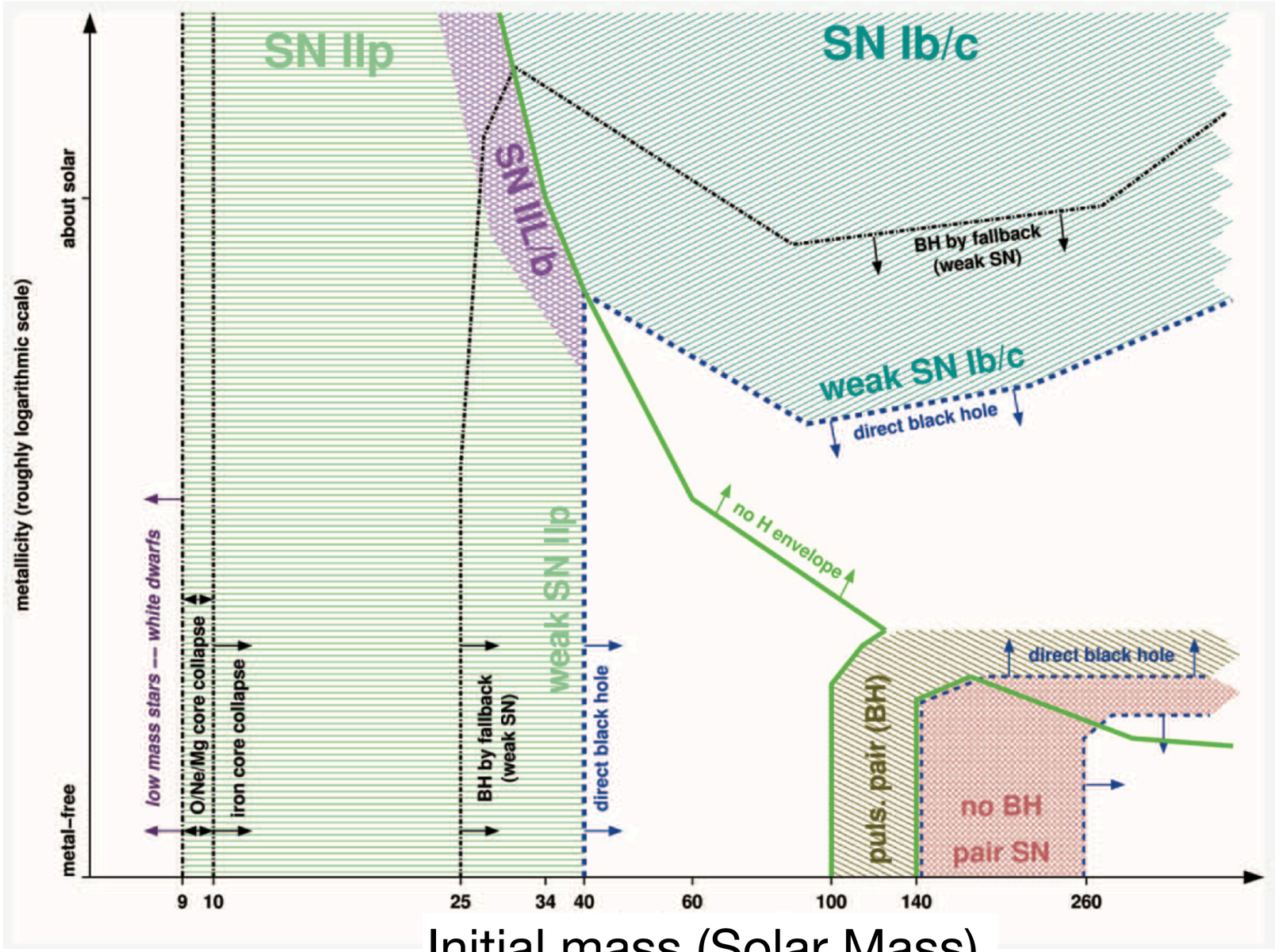
- Massive stars ($M > 8\ M_{\odot}$)
- Core: onion-like structure, with heavier elements being produced
- Final evolution depends on:
  - Initial mass
  - Metallicity
  - Mass-loss history





Explosion mechanisms

- Electron-capture SN $(8 - 10\ M_{\odot})$
- Core-collapse $(10 - 100\ M_{\odot})$
- Pulsational pair-instability $(100 - 140\ M_{\odot})$
- Pair-instability $(140 - 260\ M_{\odot})$



Pair-instability-induced supernova explosions

- The final evolutionary stage of very massive stars $(140 - 260\ M_{\odot})$
- A developed oxygen core
- The central temperature reaches $T_c \geq 10^9\ K$
- The core becomes dynamically unstable:

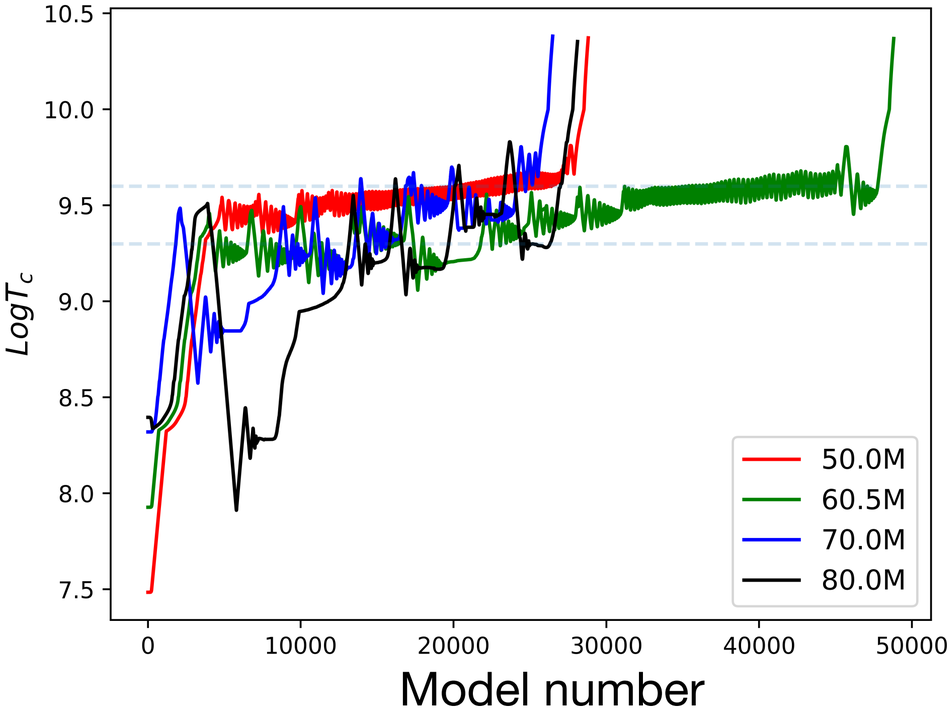
$$\Gamma_1 = \frac{d\ lnP}{d\ ln\rho} < 4/3$$

- High-energy photons produce electron-positron pairs $\rightarrow (2\gamma \rightarrow e^- e^+)$
- Radiation pressure suddenly decreases, disrupting hydrostatic equilibrium and causing the central temperature to rise further.
- The star is completely disrupted in a thermonuclear explosion, and no compact remnant is left behind.

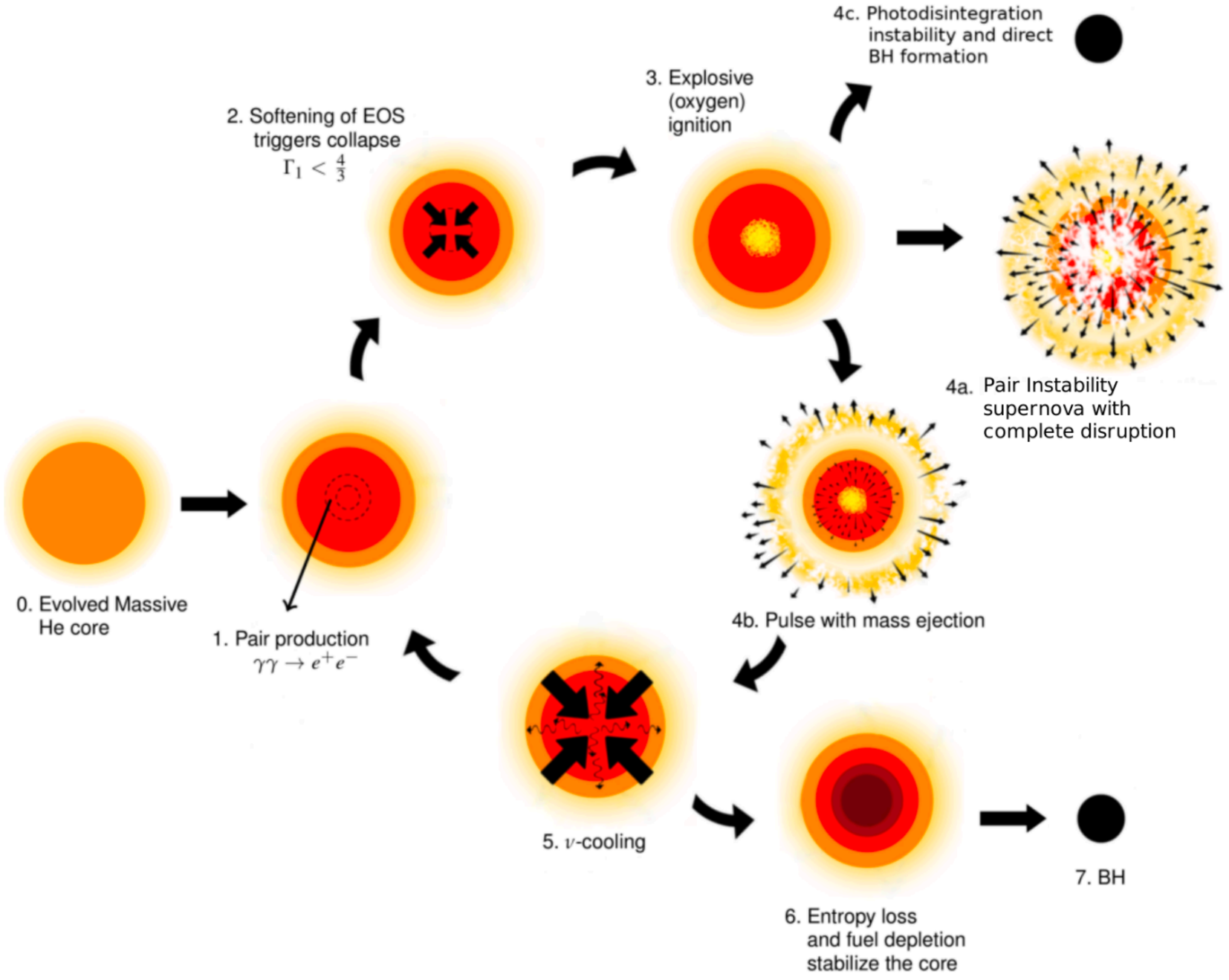
Pulsational pair-instability (PPI) mechanism

- Occurs also in massive stars $(100 - 140\ M_{\odot})$
- The star remains in hydrostatic equilibrium until helium depletion.
- We can define a mass-averaged value of the adiabatic index, since the instability develops in different stellar layers:

$$\langle \Gamma_1 \rangle = \frac{\int_0^M \frac{\Gamma_1 P}{\rho} dm}{\int_0^M \frac{P}{\rho} dm} \leq 4/3$$



- The star is not completely disrupted. Instead, one or several pulsations can occur depending on:
  - Initial mass, metallicity, rotation
- Significant mass ejection takes place, which can form circumstellar matter (CSM) around the progenitor
- Possible compact remnants: a black hole or a magnetar.



Three outcomes are possible: full disruption without a compact remnant (4a.), formation of a BH because of the photodisintegration instability **(4c.), or episodic mass loss** (4b.) and final stabilisation of the core, followed by a regular core-collapse event

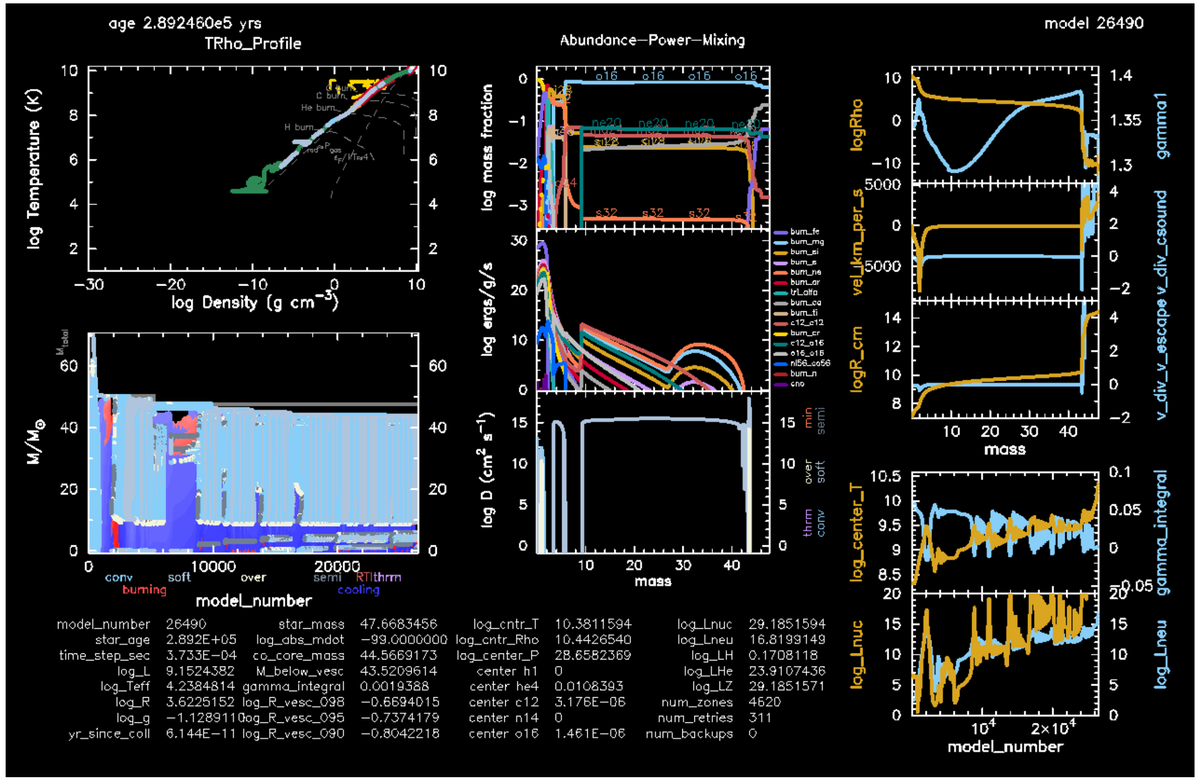
Modelling the PPI mechanism

- Modules for Experiments in Stellar Astrophysics (MESA) – a one-dimensional stellar evolution code.

- The models are evolved from the helium zero-age main sequence (He-ZAMS).

- The hydrogen envelope has already been lost during the zero-age main sequence (ZAMS), due to various mass-loss mechanisms.

- Input parameters:
  - Initial mass
  - Metallicity
  - Rotation



Modelling the synthetic light curves

- SuperNova Explosion Code (SNEC) - a one-dimensional, Lagrangian radiation-hydrodynamics code

- Simulates the hydrodynamic evolution of the stellar envelope following the explosion —> It uses the pre-supernova profiles generated by MESA

- Includes the effects of radioactive decay of Nickel and Cobalt as an energy source, but not the CSM interaction

- Therefor our approach for the modeling:

1. Stellar evolution MESA

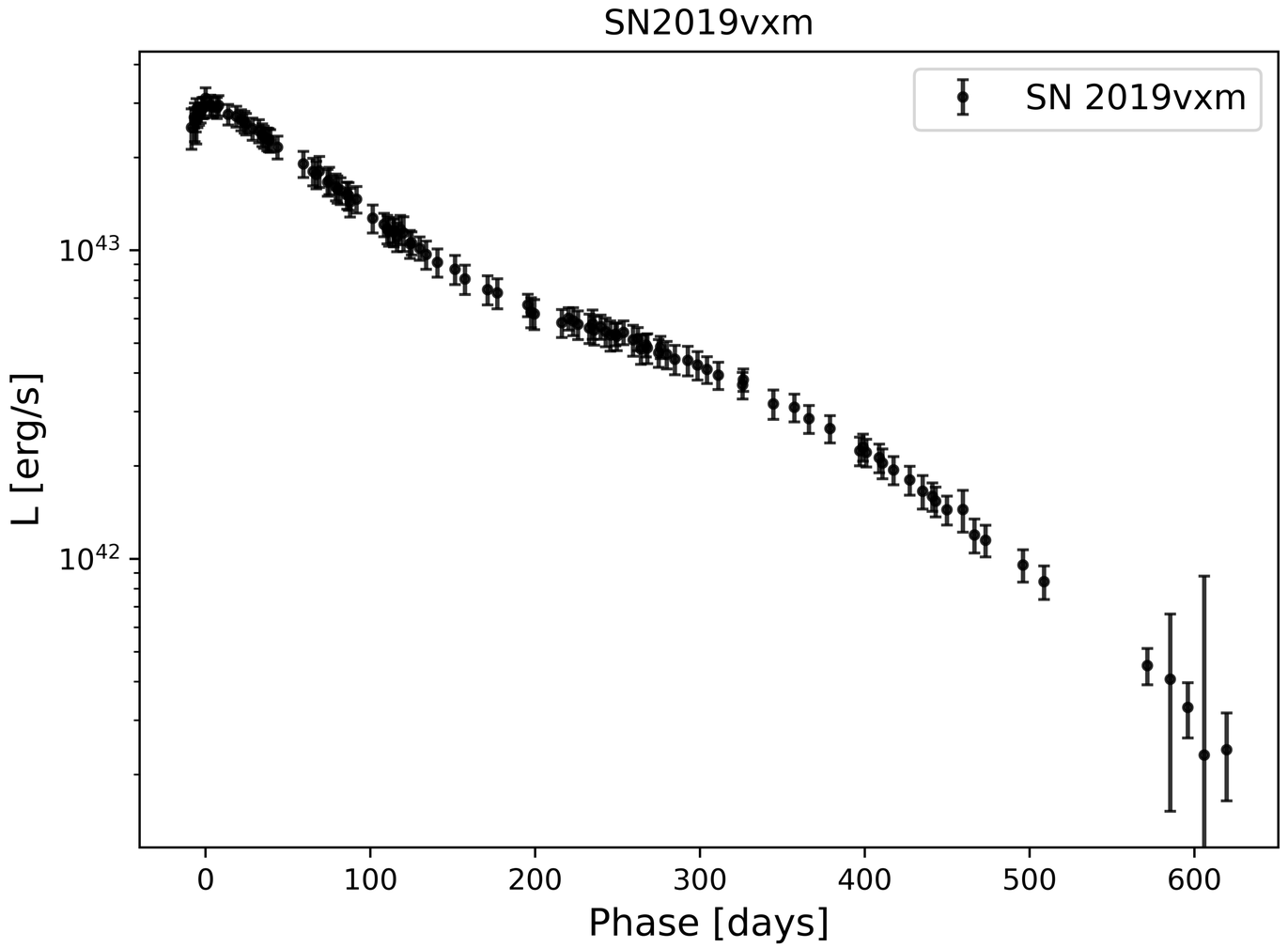
2. Input profiles SNEC

3. Generate synthetic LCs

4. Compare with SN 2019vxm observations

SN 2019 vxm

- Peculiar Type IIn SN - Slow rise and a prolonged, luminous evolution
- Strong ejecta–CSM interaction
- Mass loss: through nuclear flashes, **PPISN**, convection waves, or binary interaction
- Different studies: a single model may not adequately reproduce all phases of the observed evolution



SN 2019 vxm

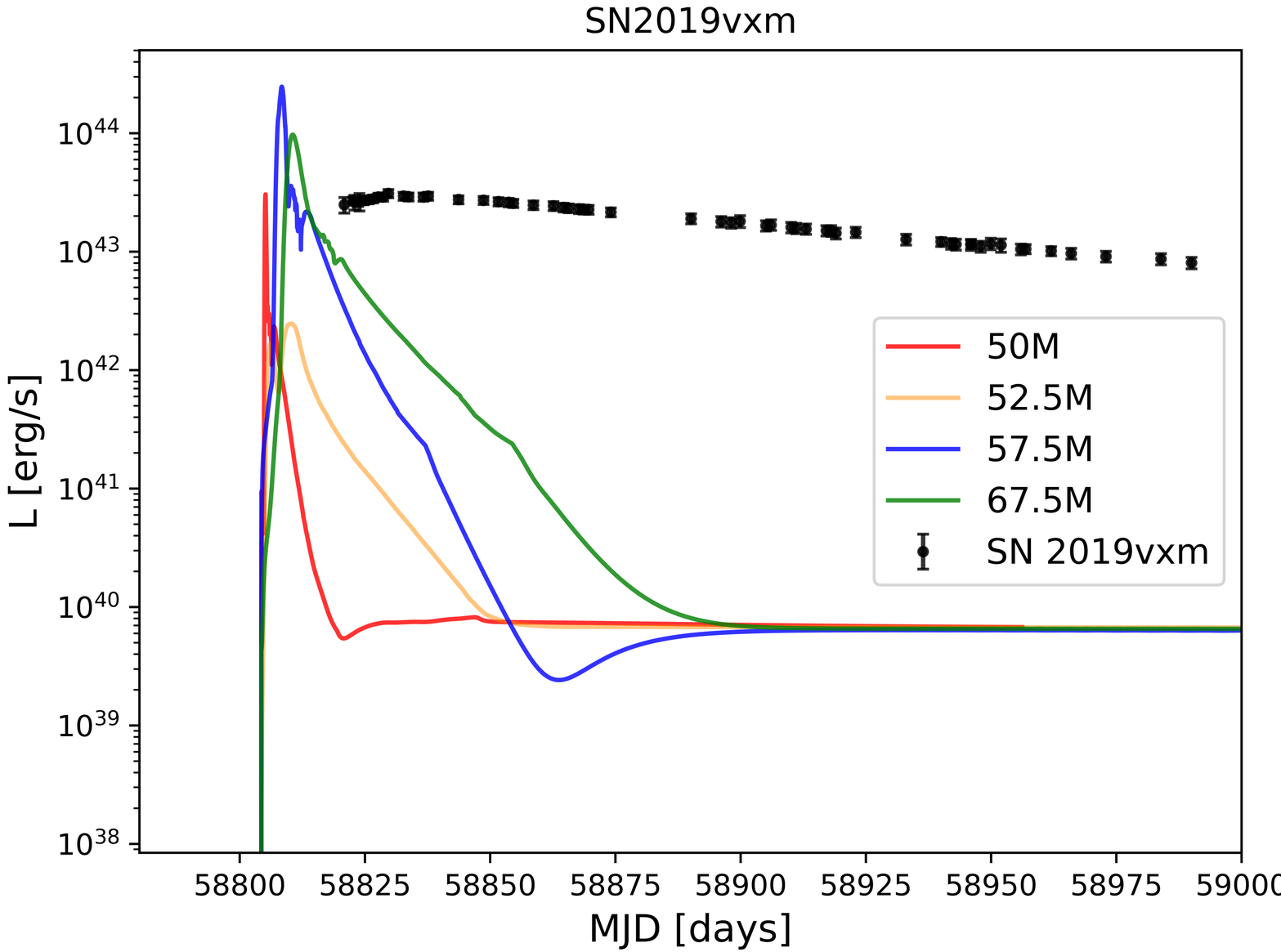
- Type IIn SN - Slow rise and a prolonged, luminous evolution
- Strong ejecta–CSM interaction
- Mass loss: through nuclear flashes, **PPISN**, convection waves, or binary interaction
- Different studies: a single model may not adequately reproduce all phases of the observed evolution

Lekes et al. 2026.	Radioactive-decay models Thin and thick CSM models	$M_{CSM} : 2 - 7\ M_{\odot}$
Rameshan et al. 2026.	UV-optical LC using MOSFIT	$M_{CSM} : 3 - 8\ M_{\odot}$
Lane et al. 2026.	Firts 200 days of the LC using MOSFIT	$M_{CSM} : 1{,}5\ M_{\odot}$

- **Main Question:** Can we approach the problem from a different direction, starting with physically motivated stellar evolution models?

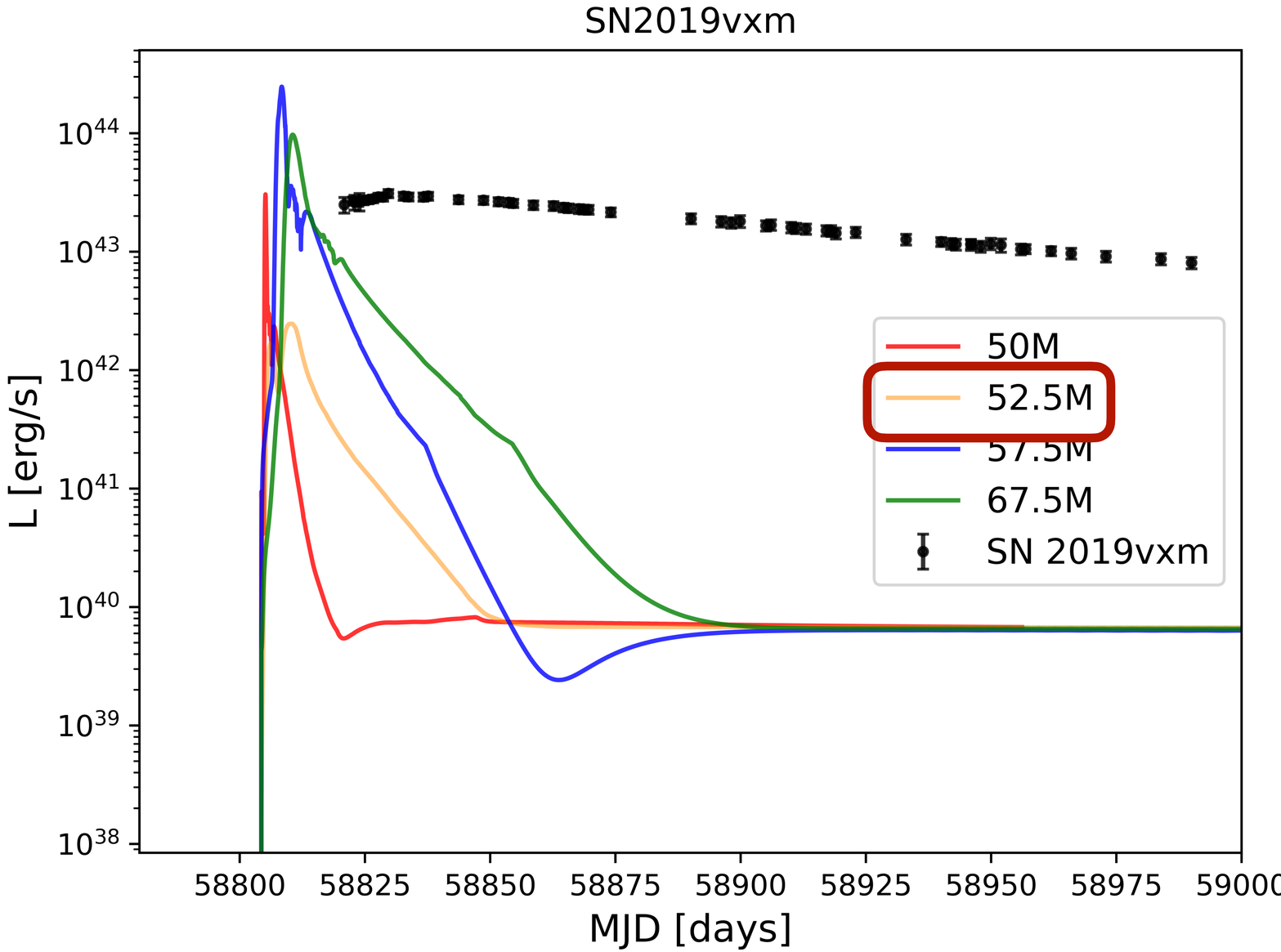
SN 2019 vxm

- Problems:
  - **No ejecta-CSM** interaction is implemented in SNEC
  - Which model is the “right” one?



SN 2019 vxm

- Problems:
  - **No ejecta-CSM** interaction is implemented in SNEC
  - Which model is the “right” one?
  - 52.5M model —> what is the missing L?

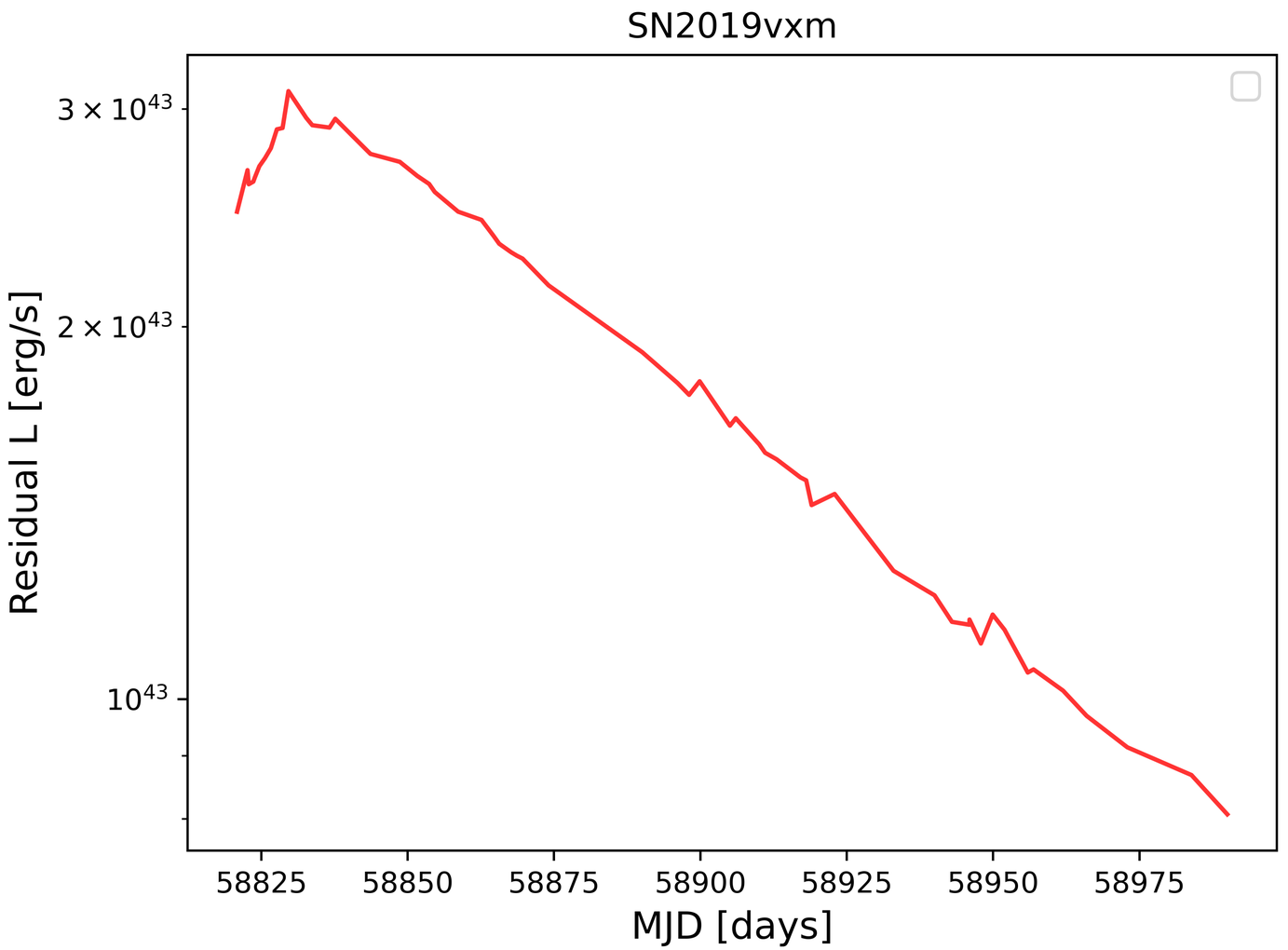


SN 2019 vxm

- This additional luminosity may be associated with ejecta–CSM interaction
- **If:** $R_{CSM} > R_{ejecta}$ then we can make this estimation:
- $\Delta L = L_{SN} - L_{52.5M}$
- Fit a dedicated CSM interaction model to the residual light curve.



- Use the resulting fit to constrain the physical properties of the CSM
(e.g. CSM mass)



Thank you for your attention!